# Massachusetts Military Reservation

MMR Doc. No.
18563

## *Final Fuel Spill-1 2005 Hydrologic Assessment of Two Ecosystems of Concern Technical Memorandum*

**March 2007**

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337105-SPEIM-FS1-TECHMEM-001

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AFCEE | Air Force Center for Environmental Excellence |
| ANOVA | analysis of variance |
| ASTM | American Society for Testing of Materials |
| AVP | Ashumet Valley Plume |
| cm/sec | centimeters per second |
| dh | difference in hydraulic head |
| dh/dz | vertical component of hydraulic gradient |
| dz | difference in elevation |
| ETD | extraction, treatment, and discharge |
| ETI | extraction, treatment, and injection |
| FS-1 | Fuel Spill-1 |
| ft bgs | feet below ground surface |
| ft msl | feet mean sea level |
| gpm | gallons per minute |
| K | hydraulic conductivity |
| MMR | Massachusetts Military Reservation |
| n | number of data pairs in T-statistic calculation |
| NWS | National Weather Service |
| PZ | piezometer reading |
| r | correlation coefficient |
| R | average antecedent rainfall rate |
| SG | staff gauge |
| SPEIM | system performance and ecological impact monitoring |
| SWP | shallow wellpoint |

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| T | T-statistic, or statistical test for the significance of the correlation between data records |
| v | average linear velocity of groundwater |
| θ | effective porosity |

# 1.0 INTRODUCTION

## 1.1 PURPOSE AND OBJECTIVES

This technical memorandum presents the results of an assessment of the hydrologic conditions at two ecosystems of concern (the Sphagnum Bog Wetland and the wetland east of the K1 Bog) near the Fuel Spill-1 (FS-1) extraction, treatment, and discharge (ETD) system (Figure 1-1). The assessment is based on data collected from April through August 2005 (the period of observation for this Technical Memorandum) under the system performance and ecological impact monitoring (SPEIM) program.

The principal objectives of this assessment were developed through recommendations in the *Final Fuel Spill-1 2004 System Performance and Ecological Impact Monitoring Report*, the *Final Fuel Spill-1 Hydraulic Evaluation Technical Memorandum*, and the FS-1 Wetland Monitoring Work Plan Project Note (AFCEE 2005a,b,c). Specifically, the objectives of this effort are to: (1) evaluate the relationship between surface water and groundwater levels at the two ecosystems of concern; (2) identify potential hydraulic impacts at the two ecosystems of concern due to the operation of the FS-1 ETD system; and (3) recommend an alternative pumping schedule for the FS-1 ETD system, if necessary, to mitigate potential hydraulic impacts at the two ecosystems of concern.

This technical memorandum has been prepared under the Air Force Center for Environmental Excellence (AFCEE) Installation Restoration Program, Contract Number F41624-03-D-8595, Task Orders 0251 and 0384, at the Massachusetts Military Reservation (MMR).

## 1.2 BACKGROUND

In the *Final Fuel Spill-1 Hydraulic Evaluation Technical Memorandum* (AFCEE 2005b), the hydraulic effects of pumping the four ETD system wells at a total of 750 gallons per minute (gpm) were shown to cause a decrease in the groundwater level at the Sphagnum Bog Wetland (piezometer 36PZ4236) of approximately 0.9 feet, and at the wetland east of the K1 Bog (piezometer 36PZ4237) of approximately 0.7 feet. The aforementioned

groundwater drawdown measurements precipitated the additional monitoring and hydrologic assessment presented in this report. The locations of these piezometers are shown on Figure 1-2.

These groundwater level declines were observed during a shutdown and restart of the ETD system in April and May, 2004 (AFCEE 2005b). However, no corresponding measurements of surface water levels were taken in either the Sphagnum Bog Wetland or at the wetland east of the K1 Bog at that time. Consequently, no conclusions could be drawn on possible cause and effect relationships between the groundwater and surface water levels at these ecosystems of concern. To remedy this information deficit, simultaneous weekly measurements of groundwater and surface water levels were collected at the Sphagnum Bog Wetland and the wetland east of the K1 Bog from April through August, 2005. These water level records, together with precipitation data and the pumping rates of the FS-1 ETD system were examined and compared statistically to evaluate the relationship between fluctuations in groundwater levels and any corresponding fluctuations in surface water levels in these two wetlands.

To provide regional context for interpretation of the hydrologic data collected at the Sphagnum Bog Wetland and the wetland east of the K1 Bog, two additional surface water records were collected at more distant (i.e., reference) wetlands that are not influenced by groundwater extraction.

## 1.3 FS-1 PLUME AND TREATMENT SYSTEM

### 1.3.1 FS-1 Plume

The FS-1 contaminant plume is located southeast of MMR in the Town of Mashpee on Cape Cod, Massachusetts (Figure 1-1). The plume is defined by the extent of groundwater contaminated with ethylene dibromide at concentrations exceeding the Massachusetts Maximum Contaminant Level of 0.02 micrograms per liter. The FS-1 plume is detached from its source area and currently extends approximately 6,400 feet in a southeasterly direction, terminating where the plume intersects the Quashnet River. Further information regarding the history and the most recent status of the FS-1 plume is

included in the *Final FS-1 2004 SPEIM Report* (AFCEE 2005a) and the FS-1 2006 Summary Letter Report (AFCEE 2007).

### 1.3.2 FS-1 Treatment System

AFCEE began operating a pilot treatment system for the remediation of the FS-1 plume in April 1999. This pilot system consisted of a single deep extraction well (36EW0005) and a shallow wellpoint (SWP) extraction system containing 175 individual SWPs. Under the pilot system, the treated groundwater was discharged via a single vertical riser pipe in the K2 Bog west ditch (Bubbler #1) and an infiltration trench along the northern edge of the K1 Bog (Figure 1-1). The FS-1 pilot system operated until October 2002 when the FS-1 treatment plant was destroyed by fire.

A new ETD system, referred to as the final FS-1 ETD system, came on-line on 30 September 2003. The new system consists of four deep extraction wells (Figure 1-1), and no longer includes the infiltration trench or the SWP system, although some of the SWPs have been retained as groundwater monitoring points. The treated groundwater is discharged to surface water via three outflow bubblers: Bubbler #1 in the K2 Bog west ditch, and Bubblers #3 and #4 in the K1 Bog ditches. The design pumping rates for the extraction wells are 150 gpm for 36EW0001, 250 gpm for 36EW0005, 150 gpm for 36EW0007, and 200 gpm for 36EW0011. Under these design pumping conditions (i.e., 750 gpm), the effluent is distributed at roughly the following rates: Bubbler #1, 350 gpm; Bubbler #3, 280 gpm; and Bubbler #4, 120 gpm. The infiltration trench used during operation of the pilot system is no longer used to discharge treated groundwater.

## 1.4 ECOSYSTEMS OF CONCERN

### 1.4.1 Sphagnum Bog Wetland

The Sphagnum Bog Wetland is a formerly cultivated cranberry bog that has been left to return to its natural state. The wetland is located immediately north of Grafton Pocknet Road, approximately 400 feet north-northeast of 36EW0005, 600 feet northwest of 36EW0007, and 300 feet west-southwest of 36EW0011 (Figure 1-1 and Figure 1-2). The

oval shaped bog has dimensions of approximately 190 feet by 160 feet. Shallow groundwater levels beneath the wetland are monitored at piezometer 36PZ4236 which is located at the southern edge of the wetland (Figure 1-2). This piezometer is screened from approximately 3 to 6 feet below ground surface (ft bgs) (between 36.78 and 33.80 feet mean sea level [ft msl]). The surface water levels at the wetland are monitored at staff gauge 36SG4236-05, which is located adjacent to 36PZ4236.

### 1.4.2 Wetland East of the K1 Bog

This wetland consists of a drainage swale with standing water that is dammed behind weir boards on the east side of the easternmost berm around the K1 bog. This linear-shaped wetland, which extends approximately 30 feet in a generally east-west direction, is located approximately 200 feet east of 36EW0005, 300 feet west of 36EW0007, and 700 feet southwest of 36EW0011 (Figure 1-1 and Figure 1-2). The shallow groundwater levels beneath the wetland are monitored at piezometer 36PZ4237, which is screened from approximately 5.3 to 7.3 ft bgs (between 32.51 and 30.51 ft msl), and is located in standing water approximately 5 feet inside the western edge of the wetland (Figure 1-2). The surface water levels at the wetland are monitored at staff gauge 36SG4237-05, which is located adjacent to 36PZ4237.

## 1.5 REFERENCE WETLANDS

### 1.5.1 Vernal Pool 2

Vernal Pool 2 is located east of the MMR in the Town of Sandwich, between Wakeby and Peters ponds off John Ewer Road (Figure 1-3). The vernal pool is oriented in a north-south direction and has dimensions of approximately 100 feet by 70 feet. No known groundwater extraction well (e.g., municipal water supply well or remedial system extraction well) is located within a distance from this vernal pool that would enable it to influence surface water levels at this wetland. Specifically, the nearest known extraction well is located more than 5,500 feet away and is part of the J. Braden Thompson plume remediation system. The surface water levels at the vernal pool are monitored at staff gauge 36SG0304-05, which is located in the southeastern portion of the vernal pool.

### 1.5.2 Abandoned Cranberry Bog

The abandoned cranberry bog reference wetland is located south of the MMR in the Town of Falmouth, east of Sandwich Road (Figure 1-3), and is oriented in a north-south direction and has dimensions of approximately 280 feet by 100 feet. As with the vernal pool reference wetland, no known groundwater extraction well (e.g., municipal water supply well or remediation system extraction well) or remediation infiltration system is located within a distance from this reference wetland that would enable it to influence surface water levels at this reference wetland. Specifically, the nearest known extraction well is part of the Ashumet Valley Plume (AVP) extraction treatment and injection (ETI) system and is more than 2,500 feet from this wetland. In addition, the western infiltration trench of the AVP ETI system is located approximately 1,300 feet from this wetland. The surface water levels at the abandoned cranberry bog are monitored at staff gauge 36SG0305-05, which is located in the southeastern portion of the abandoned cranberry bog.

## 2.0 DATA COLLECTION AND RESULTS

Hydraulic data were collected from the piezometers and staff gauges located within the ecosystems of concern and at the two reference wetlands. The monitoring frequency is presented in Table 2-1 and the monitoring locations are shown on Figure 1-2 and Figure 1-3. Construction information for the monitoring network is presented in Table 2-2 and the hydraulic monitoring data are presented in Table 2-3. Sediment cores were also collected from bog ditches at the ecosystems of concern for grain size and hydraulic conductivity analyses. The locations of the sediment cores are shown on Figure 1-2. In addition, measurements of local precipitation were obtained from the National Weather Service (NWS) station located on MMR.

### 2.1 FS-1 ETD PUMPING RATES

The average daily pumping rates for the four extraction wells during the period of observation (April-August 2005) are presented in Table 2-4. During the period of observation, the ETD system extraction wells operated at overall average daily pumping rates that were 99 percent of their design rates: (1) 36EW0001 had an average flow rate of 148 gpm; (2) 36EW0005 had an average rate of 246 gpm; (3) 36EW0007 had an average rate of 148 gpm; and (4) 36EW0011 had an average rate of 197 gpm.

A summary of downtimes for the FS-1 ETD system is presented in Table 2-5. During the period of observation, the extraction wells operated at their design flow rates for a minimum of three days prior to the collection of hydraulic data. The only exception was on 27 July 2005 when two extraction wells (36EW0005 and 69EW0011) were offline for 20 minutes and hydraulic data were collected the next day on 28 July 2005. Based on the analysis performed during the hydraulic evaluation, this short period of downtime is not considered significant and did not affect the quality of the hydraulic data collected on 28 July 2005.

### 2.2 PRECIPITATION

Precipitation measurements were recorded locally at the Otis Air National Guard Base control tower, which is an official NWS station. These measurements were reported as total inches of precipitation per day.

Daily and cumulative precipitation amounts over the period of observation are presented in Figure 2-1. The precipitation values represent the sum of rainfall amounts recorded each day. During the period of observation, rainfall of more than trace amounts (i.e., greater than or equal to 0.01 inches) were recorded on 41 separate days with a maximum daily total of 2.04 inches occurring on 06 July 2005.

During April, the total precipitation was 5.16 inches, with measurable precipitation occurring on 13 separate days. In April, the total daily precipitation exceeded 0.5 inches on four separate days and exceeded one inch once. The total precipitation measured during May was 4.67 inches. In May, measurable precipitation occurred on 13 days, with the daily totals exceeding 0.5 inches on three occasions. During June, the total precipitation was 0.47 inches, with measurable precipitation occurring on six separate days. The total precipitation measured for July was 3.37 inches with measurable precipitation occurring on five separate days. In July, the daily precipitation exceeded 0.5 inches on two separate days and exceeded one inch on one day. During August, the total precipitation was 1.64 inches, with measurable precipitation occurring on four separate days. In August, the total daily precipitation exceeded 0.5 inches on one day and exceed one inch on one day.

## 2.3 SURFACE WATER MONITORING

Manual surface water levels were collected weekly at the staff gauges located in the ecosystems of concern and the reference wetlands (Figure 1-2 and Figure 1-3).

The measured surface water records over the period of observation are plotted along with the daily precipitation record for the Sphagnum Bog Wetland (36SG4236-05) on Figure 2-2 (water levels were too low to measure after 21 July 2005); the wetland east of the K1 Bog (36SG4237-05) on Figure 2-3; the Vernal Pool 2 reference wetland (36SG0304-05) on Figure 2-4; and the abandoned cranberry bog reference wetland (36SG0305-05) on Figure 2-5.

## 2.4 GROUNDWATER MONITORING

Groundwater water levels were measured weekly at piezometers installed in the two ecosystems of concern (Figure 1-2). Piezometers were not installed at the reference wetlands.

Groundwater monitoring at piezometer 36PZ4236, located at the southern end of the Sphagnum Bog Wetland, produced 19 water-level measurements over the period of observation. However, one measurement was obviously anomalous and was not included in the data set analyzed. Specifically, the water level measured on 14 July 2005 was omitted from the data set because it was approximately one foot higher that the water levels measured either on 07 July 2005 or on 21 July 2005 even though measurable precipitation had not been recorded since 09 July 2005. The remaining sequence of 18 measurements are presented on Figure 2-6, together with the record of daily precipitation.

The record of water levels measured at piezometer 36PZ4237, located in the wetland east of the K1 Bog, is shown together with the daily precipitation record on Figure 2-7. A total of 19 measurements were taken during the period of observation, but three were identified as anomalous readings and were not included in the data set analyzed. Specifically, the water levels measured on 09 June 2005, 28 July 2005, and 18 August 2005 were omitted from the data set because they indicated unexplainably high values compared to the measurements made either the corresponding previous or following week, even though very little or no measurable precipitation was recorded for a period of days prior to the measurements. Although the anomalous piezometer reading on 28 July 2005 occurred within 24 hours from when 36EW005 and 36EW011 were off-line for 20 minutes, the reading is independent of these shutdowns, which were too brief to have affected the water level by as much as 0.2 feet based on the results discussed in AFCEE (2005b). The remaining 16 data points show a general declining trend after the cessation of frequent rainfall at the end of May 2005.

## 2.5 SEDIMENT CORES

Sediment cores were collected from the two ecosystems of concern using a hand-driven 2.0-inch diameter core barrel equipped with a clear polyvinyl chloride liner. At the

Sphagnum Bog Wetland, sediment cores were collected from two locations in the eastern portion of the perimeter bog ditch as shown on Figure 1-2: (1) within approximately five feet of piezometer 36PZ4236 at 36BH2000, and (2) approximately 118 feet northeast of piezometer 36PZ4236 at 36BH2001. At the wetland east of the K1 Bog, a sediment core was collected at 36BH2002, located within approximately five feet of piezometer 36PZ4237. Sediment cores were collected adjacent to the piezometers and staff gauge locations to correlate the resulting data on sediment properties with the hydraulic data. In addition, at the Sphagnum Bog Wetland, a second sediment sample was collected within the bog ditch as far as reasonably possible given physical access limitations from the hydraulic measuring points to address potential heterogeneity in the bog ditch sediments.

The core barrel was hand driven into the bottom of the bog ditches until refusal was encountered (approximately 1.5 ft bgs). One core sample from each location was submitted for grain size analysis by the sieving method and for measurement of hydraulic conductivity using either American Society for Testing of Materials (ASTM) method D5084 (core samples 36BH2000 and 36BH2001) or ASTM method D2434 (core sample 36BH2002) (Appendix A). Both ASTM methods are reliable and appropriate. The principal difference between the two methods pertains to the specifics of the testing equipment (i.e., the rigidity of the permeameter walls). ASTM method D5084 employs a flexible wall permeameter that is designed to enhance the accuracy of the analysis of fine-textured sediments (e.g., silt). Method D2434 uses a rigid wall permeameter that is typically used for coarse materials (e.g., sand). The particular method used in these analyses was determined following a visual inspection of the sediment cores.

Laboratory results for the sediment cores are presented in Appendix A. A summary of lithologic classification and hydrologic properties of the sediment cores are presented in Table 2-6.

### 2.5.1 Sphagnum Bog Wetland Cores

Two core samples (36BH2000 and 36BH2001) were collected from within the perimeter ditch at the Sphagnum Bog Wetland. Undisturbed sediment samples were analyzed in five to

six inch intervals throughout the length of each core. The intervals for each core are labeled top, middle and bottom on the data sheets in Appendix A. Sediments at 36BH2000 consisted of moist very dark brown sandy-silt with organic material in the upper 5.5 inches of the core (64 percent silt and clay by weight). Below this sandy-silt layer, the observed substrate consisted of very dark brown sandy-silt with gravel (39 percent silt and clay by weight) in the middle interval of the core, between a depth of 5.5 inches below ground surface (in bgs) and 11.5 in bgs. The bottom interval of the core, between depths of 11.5 in bgs and 17.5 in bgs, consisted of very dark brown clayey-sand (53 percent silt and clay by weight). The measured hydraulic conductivity of sediments from this core ranged from $5.9 \times 10^{-7}$ centimeters per second (cm/sec) to $5.8 \times 10^{-6}$ cm/sec ($1.7 \times 10^{-3}$ feet/day to $1.6 \times 10^{-2}$ feet/day). The measured hydraulic conductivities were consistent with the expected range of values for these sediment textures (Freeze and Cherry 1979).

Sediments at 36BH2001, located approximately 118 feet northeast of 36BH2000, were composed of moist dark grayish brown sand with organic material in the upper eight inches of the core (93 percent sand). Below the sand layer, the sediment consisted of black clayey-gravel with silt, sand and organic material (60 percent gravel by weight) in the middle interval of the core between a depth of 8 in bgs and 14 in bgs. The bottom interval of the core, between a depth of 14 in bgs and 20 in bgs, was comprised of very dark brown sandy-clay (86 percent sand by weight). The measured hydraulic conductivity of sediments from this core ranged from $3.6 \times 10^{-7}$ cm/sec to $4.5 \times 10^{-6}$ cm/sec ($1.0 \times 10^{-3}$ feet/day to $1.3 \times 10^{-2}$ feet/day. Although generally the grain size was more coarse at 36BH2001 compared to the 36BH2000 core, the measured hydraulic conductivities were very similar for both cores.

### 2.5.2 Wetland East of the K1 Bog Core

Sediments at 36BH2002 were comprised primarily of grayish brown sand with gravel, with trace silt and clay to a depth of 19.5 inches. The measured hydraulic conductivity of the undisturbed sediment from this core was $1.3 \times 10^{-3}$ cm/sec (3.7 feet/day). This value reflects the coarse grain size observed, and is within the range of values of saturated hydraulic conductivity corresponding to this sediment texture (Freeze and Cherry 1979).

# 3.0 DATA ANALYSIS

The data collected during the observation period from the ecosystems of concern and the two reference wetlands are assessed in this section with respect to the project objectives listed in Section 1.1.

## 3.1 SPHAGNUM BOG WETLAND

Identification of causes and effects in the hydrologic data records at the Sphagnum Bog Wetland is complicated because both the surface water and the groundwater levels should be expected to respond to precipitation events. Therefore, similarities between the surface water and groundwater records may be due partly to their common response to precipitation and partly to direct hydrologic interaction between them. Among the four data records that were examined, the precipitation and the ETD pumping rates were considered to be independent variables, while the groundwater and surface water records were each considered to be potentially dependent on all of the other factors.

### 3.1.1 Groundwater

#### 3.1.1.1 Groundwater Correlation to Precipitation

It is apparent from Figure 2-6, which shows both the water level data in 36PZ4236 and precipitation over the observation period, that the groundwater levels were higher and rainfall was more frequent during the first half of the observation period. After the end of May, there were fewer rainfall events, and the groundwater levels declined fairly consistently. Beyond these qualitative observations, it is difficult to correlate the groundwater and precipitation records without further processing of the rainfall data.

**Precipitation Averaging**. The precipitation record, as shown in Figure 2-6, is characterized by rainfall events of relatively short duration separated by periods of little or no measurable rainfall. The effect of these precipitation events on groundwater levels depends on their magnitude, duration, and the length of the intervals between rainfall events. Therefore, correlating the groundwater levels to the precipitation record, it was

useful to consider the average antecedent rainfall for periods of several days or weeks preceding each measurement of the groundwater level. This averaging filters out some of the high frequency fluctuations in the precipitation rate, while preserving the longer-term tendencies of the record.

The precipitation record at a variety of antecedent averaging periods ranging from one day (no averaging) to 80 days is shown in Figure 3-1. The dates when groundwater levels were measured at piezometer 36PZ4236 are also indicated on the figure by triangular symbols. Figure 3-1 shows that, if daily average precipitation rates were correlated to the groundwater levels, many of the groundwater measurements would correspond to zero rainfall. This produces a relatively low statistical correlation between the two records because groundwater levels change much more slowly than the rates of precipitation. Correlation of groundwater levels to the longer averaging periods of the precipitation record gives a more realistic description of the hydrologic response, and produces higher statistical correlations.

**Correlation Coefficient**. The correlation coefficients produced by correlating the piezometer 36PZ4236 water-level record to the precipitation record averaged over a range of antecedent periods are listed in Table 3-1. All correlation coefficients presented in this technical memorandum are Pearson correlation coefficients. A Pearson correlation coefficient is a scaled statistical parameter that ranges from -1 to 1, and indicates the degree of similarity between two data records in terms of their simultaneous deviation from their own means. An r-value of 1.0 indicates perfect agreement between the two records, a value of -1.0 would indicate a perfect inverse relationship, while a value of 0 indicates no relationship. Several of the lower r-values in this technical memorandum (including many below 0.5) are not significantly different from zero, statistically, even though the reported r-value is the best estimate of the correlation. Whether or not a given r-value is statistically significantly different from zero depends on the number of data pairs available in the data set and the distribution of the data. Consequently, too much credence should not be given to minor differences between relatively small r-values.

For the precipitation/groundwater level data pairs at the Sphagnum Bog Wetland, the highest correlation coefficient, r = 0.964, was obtained at the 70-day antecedent averaging period. A value of r = 0.964 shows a strong positive relationship between the 36PZ4236 water-level record and the 70-day average antecedent rainfall. The similarity between the two records is shown graphically in Figure 3-2.

It should be noted, however, that the particular duration of the antecedent period is less important than the actual correlation between groundwater levels and time-averaged precipitation. While the 70-day average antecedent rainfall has the highest associated correlation coefficient, the results in Table 3-1 indicate that averaging periods as low as 50 days also have a fairly high correlation coefficient with groundwater levels (r = 0.894). The physical significance of the specific averaging period selected, therefore, is somewhat vague. Use of antecedent averaging is based on the reasonable assumption that the water level obtained from a particular measurement is influenced by the combined effects of all precipitation events that occurred for some time before the measurement was taken. It may also be reasonable to assume that more recent events have more influence than those in the more distant past. That assumption could be accommodated by assigning varying weights to the individual precipitation measurements that decrease with increasing antecedent lag time.

For this analysis, however, simple averaging was used so that the precipitation rate for each day in the averaging period was weighted the same. Thus, for a 70-day antecedent averaging period, the average precipitation rate was determined from measurements with a mean antecedent lag time of 35 days. When water levels at a measuring point are correlated with precipitation using this averaging period, it is tacitly assumed that an assemblage of unspecified hydrologic factors/processes (e.g., depth to groundwater, infiltration rate), each with its own characteristic influence on response time, results in an average delay of 35 days between the application of precipitation to the ground surface and the maximum response at the groundwater measuring point. Similarly, lesser duration antecedent averaging periods, which still have high correlation coefficients, would have shorter associated lag times and their own suite of corresponding assumptions regarding response times for influential hydrologic factors and processes.

**Significance of the Correlation.** A statistical test for the significance of the correlation uses the T-statistic:

$$T = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

where n is the number of data pairs used in calculating the correlation coefficient.

A low value of T indicates that the two data records may have no more meaningful relationship than n pairs of randomly selected numbers. A high T value means that there is little probability of the data records being unrelated (i.e., the probability that the two data pairs are related is high). The probability of no meaningful relationship existing is determined by comparing the T-statistic to Student's T probability distribution. In the case of the correlation between 70-day average precipitation and the 36PZ4236 piezometer readings ($r = 0.964$), the T-statistic shows less than 1-percent probability that the groundwater level at the Sphagnum Bog Wetland is statistically unrelated to the 70-day average precipitation (i.e., the probability that the groundwater level at the Sphagnum Bog Wetland is statistically related to the 70-day average precipitation is very high).

#### 3.1.1.2 Groundwater Correlation to ETD Pumping

The daily average total pumping rate of the four FS-1 ETD system wells is plotted together with the measured groundwater water levels at piezometer 36PZ4236 in Figure 3-3. The pumping records show that all four extraction wells operated near their design pumping rates most of the time. Temporary reductions in the daily average pumping rates were generally caused by maintenance operations at the groundwater treatment plant or system shutdowns due to power failures, and affected all four wells simultaneously. No obvious relationship between the changes in ETD system pumping and groundwater levels can be seen by examining the raw data records.

Experience from the system shutdown and restart that was conducted in 2004 (AFCEE 2005b) showed that the water levels at piezometer 36PZ4236 do not react instantaneously to changes in the pumping rate. In fact, the hydrograph collected during the initial

shutdown of that test shows that the recovery of water levels was approximately 50 percent complete after two days and about 90 percent complete after approximately six days (Figure 4-1 in AFCEE 2005b). Therefore, to reveal hidden relationships between groundwater levels and pumping rates, it could be advantageous to remove the high frequency changes from the pumping record by averaging. The total ETD system rates averaged over periods ranging from one to seven days are shown on Figure 3-4. To highlight the magnitude of the pumping changes, the rates are presented as percentages of the total design rate, which is 750 gpm. The dates when water levels were measured at piezometer 36PZ4236 are shown with triangular symbols. The plot shows that the system operated very close to its total design rate except for minor reductions of a few percent, and two days in May and July when the daily average fell to approximately 60 percent.

Statistical correlations between the 36PZ4236 piezometer readings and the ETD system pumping rates were calculated for each averaging period from one to seven days. The resulting correlation coefficients are listed in Table 3-2. The correlation coefficients are all less than 0.5 and the individual values change substantially from one averaging period to the next. This indicates that there is little demonstrable relationship between the records for Sphagnum Bog Wetland groundwater levels and average pumping rate. However, this result occurred because the changes in pumping rate were relatively slight and/or occurred over brief periods of time. Accordingly, to conclude that the operation of the FS-1 ETD system at current design rates does not affect groundwater levels at the Sphagnum Bog wetland would be misleading. The relationship between pumping and groundwater levels at the Sphagnum Bog wetland was determined during the 2004 pumping test and is documented in both the *Final Fuel Spill-1 Hydraulic Evaluation Technical Memorandum* dated June 2005 and the *Final Fuel Spill-1 2004 System Performance and Ecological Impact Monitoring Report* dated June 2005.

### 3.1.2 Surface Water

#### 3.1.2.1 Surface Water Correlation to Precipitation

Water-level monitoring at staff gauge 36SG4236-05, located adjacent to the piezometer at the southern edge of the Sphagnum Bog Wetland, produced 16 measurements between 07 April and 21 July 2005. The measured water-level record together with the daily precipitation record are shown on Figure 2-2. The correspondence between higher rainfall frequency and higher water levels during the first part of the record is again obvious. Hydrologic considerations suggest that the surface water elevation in the Sphagnum Bog Wetland should be influenced by antecedent precipitation, just as the groundwater levels are. However, the timing of surface water and groundwater responses to rainfall events are likely to be different. Therefore, the record of water levels from staff gauge 36SG4236-05 was correlated to antecedent rainfall over a range of averaging periods to determine which periods would produce the closest match. The results are listed in Table 3-3.

The highest correlation between staff gauge readings and average antecedent precipitation was found for the 35-day averaging period. The correlation coefficient of 0.958 for this period (35 days) indicates a relatively high degree of correlation. Given this high of a correlation coefficient, it is not surprising that a test of correlation significance using the T-statistic shows less than 1-percent chance of the records being unrelated (i.e., that staff gauge measurements at the Sphagnum Bog Wetland and the 35-day antecedent precipitation are related). This is further reinforced by the graphical presentation of the two records in Figure 3-5.

#### 3.1.2.2 Surface Water Correlation to Groundwater

The surface water and groundwater records that were collected at the Sphagnum Bog Wetland are graphically compared on Figure 3-6. The surface water record (36SG4236-05) is shorter than the groundwater record because surface water was not present at this location during the period of observation after mid-July 2005. However, for the times when both records have data points, the similarity between the two is quite obvious.

Statistical correlation of the 13 data pairs that are common between the two records gives a correlation coefficient of $r = 0.805$. While this indicates a fairly high degree of correlation, it is not as high as the correlations of either the groundwater record or the surface water record with antecedent precipitation. Since both water-level records are closely tied to precipitation, it is not surprising that they would also be similar to each other. The statistical problem is to determine whether there is a statistically significant relationship between these two water-level records independent of their common ties to precipitation.

This determination was attempted by performing a multiple linear regression analysis in which the surface water record was regressed on both the precipitation and the groundwater records. The precipitation record used in this analysis was the 35-day antecedent running average. The results of the regression analysis were an estimated prediction equation and statistical significance values for each of the regression coefficients. The estimated equation was:

$$SG = 35.8 + 3.84\ R + 0.105\ PZ$$

where:

SG = staff gauge reading (ft msl)
PZ = piezometer reading (ft msl)
R = 35-day average antecedent rainfall rate (inch/day)

The statistical significance of the regression coefficients was evaluated by analysis of variance (ANOVA). With ANOVA, the total variation in the data sets is partitioned into different potential sources of variation corresponding to the three terms on the right hand side of the regression equation. When the variation due to changes in these variables is sufficiently large relative to the overall variation in the data, the probability that the predictor variable should be dismissed as unimportant diminishes. The results of this analysis were as follows:

| Analysis of Regression Coefficient Significance | | | |
|---|---|---|---|
| **Coefficient** | **Estimated Value** | **T-Value** | **Probability of No Significance** |
| Intercept | 35.774 | 4.978 | 0.000555 |
| R Coefficient | 3.863 | 5.459 | 0.000277 |
| PZ Coefficient | 0.105 | 0.544 | 0.592 |

The ANOVA results show a very strong contrast in the levels of significance between the effects of precipitation rate on staff gauge water levels and the piezometer readings on staff gauge water levels. The T distribution suggests very low probability (0.0277 percent) that the surface water levels at the Sphagnum Bog Wetland are unrelated to precipitation, but relatively high probability (59.2 percent) that these surface water levels are unrelated to groundwater levels when the linkage through precipitation is removed. Clearly, this difference in probabilities is meaningful considering that the probability ranges from 0 to 1. In statistics, a probability above a threshold on the order of 5 percent (i.e., anything less than 95 percent probability that two data records are related) is often considered sufficient for concluding that any observed relationship between two variables is simply due to random noise. The large difference in probabilities also indicates that given all of the variation in the surface water values, the amount of variation explained by precipitation is very significant, whereas the amount explained by groundwater levels falls within the range of what could be expected from random variation.

Another notable fact about the two data records shown in Figure 3-6 is that the surface water level was consistently about two feet higher than the groundwater level. This difference in water levels persisted throughout the period of observation, even though there were relatively long intervals without significant precipitation in late June and July. This substantial head difference between the surface water levels in the bog and the underlying groundwater suggests that there may be a hydraulic reason for the statistical lack of a cause-and-effect relationship between the two records (e.g., low permeability of

the sediments underlying the ditch bottom inhibiting infiltration). This is examined in more detail below in Section 3.1.3.

### 3.1.3 Analysis of Sediment Cores

The extremely low hydraulic conductivity of the sediment cores from the perimeter ditch around the Sphagnum Bog Wetland (equivalent to the low end of silt range and high end of clay range) is consistent with the results of the grain size analysis (Table 2-6) and supports a hypothesis that the surface water in the bog ditch is likely to be perched and not in direct hydraulic communication with the underlying groundwater. Under those conditions, the decline in surface water level would be largely affected by evaporation. This hypothesis is consistent with the results of the statistical analysis presented above in Section 3.1.2.2, which concluded that it was highly probable (59.2 percent) that the records of surface water and groundwater levels at the Sphagnum Bog Wetland were unrelated.

The hypothesis that the surface water in the Sphagnum Bog Wetland is perched can be explored further quantitatively by plugging the geometric mean of the lowest measured value of hydraulic conductivity from each of the two sediment cores from the bog ditch ($K = 1.3 \times 10^{-3}$ feet/day) into Darcy's Law in one dimension to approximate infiltration:

$$v = (K\ dh/dz)/\theta$$

In this equation, v is the average linear vertical velocity of water through the sediments immediately underlying the bog ditch (thus approximating infiltration rate); dh/dz is the vertical component of hydraulic gradient over the interval (dz) between the ground surface (i.e., the elevation of the bottom of the bog ditch at the location of the staff gauge 36SG4236-05 [39.48 ft msl]) and the mid-point elevation of the screen in 36PZ4236 (35.29 ft msl); and θ is the effective porosity (assumed to be 50 percent for a substrate of silt/clay composition [Driscoll 1986]).

By considering both the maximum head difference between the staff gauge and the piezometer (dh = 2.48 feet) and the average head difference (dh = 2.12 feet) over the observation period, the average liner velocity ranges between 5.8 inches/year (based on the average head difference over the period of observation) and 6.8 inches/year (based on the maximum head difference).

To put these infiltration estimates into context, the surface water record was examined to identify the rate of change in surface water levels in the Sphagnum Bog Wetland over a period of no precipitation. During the 21-day period between 02 June and 23 June 2005, no precipitation was recorded and the water level decline at 36SG4236-05 was 0.39 feet. The corresponding annualized rate of change in surface water level at this staff gauge is therefore 81.4 inches/year in the absence of precipitation during the period of observation. As a result, the estimate of infiltration of between 5.8 and 6.8 inches/year over the same period does not account for the total rate of water level decline observed in the Sphagnum Bog Wetland ditch. Clearly, processes other than infiltration (e.g., evaporation) affect surface water decline to a greater degree, consistent with the hypothesis that surface water is perched in the bog ditch. Accordingly, based on the results of both the multiple linear regression (Section 3.1.2.2) and the analysis of the sediment cores, it is concluded that there is no direct connection between fluctuations in surface water and groundwater levels at the Sphagnum Bog Wetland.

## 3.2 WETLAND EAST OF THE K1 BOG

As with the data from the Sphagnum Bog Wetland, the groundwater and staff gauge measurements at 36PZ4237 and 36SG4237-05, respectively, were assessed along with precipitation statistically to understand potential relationships between the data sets.

### 3.2.1 Groundwater

#### 3.2.1.1 <u>Groundwater Correlation to Precipitation</u>

Figure 2-7 shows the record of water levels measured at piezometer 36PZ4237 together with the daily precipitation record. A total of 19 measurements were taken during the

period of observation, but three were identified as anomalous readings and deleted. The remaining 16 data points show a general declining trend after the cessation of frequent rainfall at the end of May.

Following the procedures used on the data from the Sphagnum Bog Wetland, the piezometer 36PZ4237 readings were statistically correlated to the precipitation record using a range of antecedent averaging periods. The results are listed in Table 3-4. The maximum correlation, r = 0.932, was found for the 70-day average antecedent precipitation. This correlation coefficient is of a magnitude similar to the correlation found at the Sphagnum Bog Wetland. As expected, application of the T test indicates that there is less than 1 percent probability that the groundwater level is unrelated to the rates of antecedent precipitation. The relationship between the two records is illustrated graphically in Figure 3-7.

#### 3.2.1.2 Groundwater Correlation to ETD Pumping

To test the statistical relationship between groundwater levels and ETD system pumping rates, the water level readings at piezometer 36PZ4237 were correlated to a range of average antecedent pumping rates. As shown in Table 3-5, the correlation coefficients were all of relatively small magnitude and ranged from negative to positive. This indicates that the data set cannot demonstrate a statistically significant relationship between the records (i.e., between average groundwater pumping rates and the groundwater elevation at 36PZ4237). However, this result occurred because the changes in pumping rate were relatively slight and/or occurred over brief periods of time. Accordingly, to conclude that the operation of the FS-1 ETD system at current design rates does not affect groundwater levels at the wetland east of the K1 Bog would be misleading. The relationship between pumping and groundwater levels at the wetland east of the K1 Bog was determined during the 2004 pumping test and is documented in both the *Final Fuel Spill-1 Hydraulic Evaluation Technical Memorandum* dated June 2005 and the *Final Fuel Spill-1 2004 System Performance and Ecological Impact Monitoring Report* dated June 2005.

### 3.2.2 Surface Water

#### 3.2.2.1 Surface Water Correlation to Precipitation

Figure 2-3 shows the record of 21 water-level measurements collected from staff gauge 36SG4237-05, located at the west edge of the wetland. The dominant feature of this record is that the surface water levels were constant at 34.43 ft msl, within the accuracy of the measurements, throughout April, May, and June. The reason for this is that the water levels in the wetland are regulated by weir boards in the discharge channel between the wetland and the K1 Bog. The weir was designed to allow water to drain to the K1 bog ditches by underflowing the weir boards through a gap between the first board and the bottom of the weir, and by overflowing the boards. During July and August, the weather was relatively dry and the surface water levels declined approximately 0.81 feet below the crest of the weir. This is approximately twice the amount of decline observed in the groundwater (at piezometer 35PZ4237) during that period (Figure 2-7).

Because the measurements of surface water levels were controlled by the weir during the first portion of the observation period, correlation to precipitation was only meaningful for the eight measurements that were taken after June 23. Those eight water levels were correlated to the precipitation record for a range of averaging periods, with the results shown in Table 3-6. The maximum correlation coefficient, r = 0.970, was obtained with the 78-day average antecedent precipitation. Even though only eight data points were used, this correlation coefficient is high enough to indicate a probability of less than 1 percent that the surface water and precipitation records are not related. The two 8-point data records are shown graphically in Figure 3-8.

#### 3.2.2.2 Surface Water Correlation to Groundwater

Figure 3-9 is a simultaneous plot of the water level records that were collected at staff gauge 36SG4237-05 and at adjacent piezometer 36PZ4237. On average, the groundwater levels were approximately half a foot higher than the surface water levels. During the period after 07 July, when the surface water was no longer being maintained by the weir,

both water levels declined. The surface water level declined more than twice as much as the groundwater level.

While much of the staff gauge record was masked by the controlling influence of the weir boards, it has been shown that under dry weather conditions both of these records were strongly influenced by precipitation. Ideally, it would be possible to use multiple regression and analysis of variance to separate the apparent influences of precipitation and groundwater levels on the staff gauge reading, as was done with the data from the Sphagnum Bog Wetland. However, only six reliable data points are available for piezometer 36PZ4237 during the period when the surface water was no longer being stabilized by the weir. This low number of measurements is not enough to support such an analysis.

### 3.2.3 Analysis of Sediment Cores

No specific assessment was performed using the results of the grain size and hydraulic conductivity analyses on the sediment core from this wetland. Consistent with the results of the grain size analysis, the high value of K measured in the sediment core (3.7 feet/day) suggests a direct hydraulic connection between the surface water and underlying groundwater at this wetland. However, this conclusion is inconsequential with respect to the question of whether the operation of the FS-1 ETD system at design pumping rates directly affects the surface water in the wetland. The local groundwater elevation is consistently higher than the adjacent surface water level at this wetland, and the latter is controlled by weir boards (see discussion above in Section 3.2.2.2). Consequently, changes in groundwater levels caused by the operation of the FS-1 ETD system do not affect the surface water levels in the wetland and do not cause groundwater to cease discharging to the wetland.

## 3.3 REFERENCE WETLANDS

Surface water data at the reference wetlands were analyzed along with the precipitation record to provide regional context for interpretation of the hydrologic data collected at the Sphagnum Bog Wetland and the wetland east of the K1 Bog.

### 3.3.1 Vernal Pool 2

Vernal Pool 2 is located more than two miles north-northeast of FS-1. Staff gauge 36SG0304-05 was installed at this location (Figure 1-3) and 20 water level measurements were collected between 07 April and 25 August 2005. These water level elevations are presented graphically, together with the daily precipitation record on Figure 2-4.

During April and May, the surface water levels at Vernal Pool 2 increased slightly less than 1 foot, reaching a peak on 09 June. This early part of the record corresponds to the period of relatively frequent precipitation. After the end of May, the frequency of rainfall events decreased, and the elevation of the water level in the wetland declined.

To examine the relationship between the staff gauge and precipitation records in more detail, correlation coefficients were calculated for different averaging periods of the precipitation record. The results are listed in Table 3-7. In spite of the apparent qualitative relationship suggested in Figure 2-4, the calculated correlation coefficients are all fairly low, with a maximum r-value of 0.469 for the 70-day average antecedent rainfall. At averaging periods above 74 days, the correlations are negative. Seventy days is approximately equal to the length of the rising and falling periods of the staff gauge record shown in Figure 2-4. Apparently, the water levels in this wetland have little dependence on variations in the precipitation rate that occur over periods of less than about two months.

The record of surface water levels compared to the 70-day average antecedent precipitation rate are shown on Figure 3-10. The correspondence during the period of falling water levels is fairly clear. When the water levels were rising, however, the relationship is weak. This could be because the water levels in April and May were

dominated by influences other than precipitation, or because there is a non-linear relationship that cannot be detected by the methods used in this evaluation.

### 3.3.2 Abandoned Cranberry Bog

The abandoned cranberry bog wetland is located more than three miles south-southwest of FS-1 (Figure 1-3). Staff gauge 36SG0305-05 was installed in this wetland, and 20 water level measurements were collected between 07 April and 25 August 2005. These measurements are plotted, together with the daily precipitation record on Figure 2-5. The graph shows relatively stable water levels in April and May, followed by a fairly steady decline as the weather conditions became dryer. The surface water levels in the wetland fell approximately 1.4 feet between 26 May and 25 August 2005.

The statistical correlations between the staff gauge readings and the precipitation record, for a range of antecedent averaging periods, are listed in Table 3-8. These correlations are relatively high, with a maximum of r = 0.960 for the 64-day average. Application of the T test indicates less than a 1 percent probability that the records are not related.

The staff gauge record and the 64-day average precipitation record are plotted together on Figure 3-11 The obvious close correspondence reinforces the conclusion that the water level in this wetland is strongly influenced by antecedent precipitation.

# 4.0 SUMMARY OF CONCLUSIONS

The principal conclusion from the results of the analyses presented in this technical memorandum is that even though the FS-1 ETD system when operating at design pumping rates results in groundwater level declines ranging up to 0.9 feet at the two ecosystems of concern, the local surface water levels at these two wetlands are not affected. At the Sphagnum Bog Wetland, surface water is perched in the bog ditch and not directly hydraulically connected to groundwater. At the wetland east of the K1 Bog, surface water fluctuations are controlled by factors (e.g., weir boards) other than changes in groundwater levels. Specific conclusions that support this general conclusion are presented in the following sections.

## 4.1 SPHAGNUM BOG WETLAND

- The groundwater levels at the Sphagnum Bog Wetland are strongly influenced by precipitation. The results of the statistical analysis indicate both a strong Pearson correlation, $r = 0.946$, between groundwater levels and precipitation, and a T–statistic that implies that there is less than 1 percent probability that the groundwater levels at the Sphagnum Bog Wetland are statistically unrelated to the 70-day average precipitation. Changes in the groundwater level at this wetland of more than 1.3 feet were associated with precipitation rate variations observed during the observation period.
- The relationship between groundwater levels at the Sphagnum Bog Wetland and the relatively mild variations observed in the pumping rates of the FS-1 extraction wells during the observation period was found to be weak. This outcome likely occurred because the degree of variation in the pumping rates during the observation period was very low. As reported earlier (AFCEE 2005b), the hydraulic effect of turning off all of the FS-1 extraction wells for a period of days was a groundwater rise of approximately 0.9 feet at piezometer 36PZ4236.
- Surface water levels in the Sphagnum Bog Wetland were found to be strongly correlated to precipitation. Specifically, the results of the statistical analysis indicate both a high degree of correlation, $r = 0.958$, between surface water fluctuations and precipitation rate, and a T-statistic that implies that there is less than 1 percent probability that the staff gauge measurements are statistically unrelated to the 35-day average precipitation.
- While the statistical analysis of the water levels did not show that there is no relationship between the groundwater and surface water levels at the Sphagnum Bog Wetland, it did show that the effects of groundwater fluctuations on the surface water in the adjacent bog ditch were negligible in comparison to the influence of natural

variations in precipitation rate. Specifically, it was determined through multiple linear regression and subsequent analysis of the variance that there is a high probability (59.2 percent) that fluctuations in surface water levels are unrelated to those in groundwater levels.

- Surface water levels at the Sphagnum Bog Wetland were consistently about 2 feet higher than the groundwater levels throughout the 5-month period of observation.
- The results of grain size and laboratory hydraulic conductivity analyses on two sediment cores from the perimeter ditch at the Sphagnum Bog Wetland reveal that the permeability of the sediments immediately below the bottom of the ditch is very low (geometric mean of $K = 1.3 \times 10^{-3}$ feet/day, which corresponds to a clay/silt composition). Based on these results, surface water in the Sphagnum Bog Wetland ditch is considered to be perched (i.e., surface water is inhibited from infiltrating and therefore not in direct hydraulic connection with the underlying groundwater). This conclusion is consistent with the results of the aforementioned statistical analysis indicating that fluctuations in surface water levels were not strongly related to changes in groundwater levels.
- Estimates of the average linear vertical velocity of groundwater immediately under the perimeter ditch of the Sphagnum Bog Wetland, calculated to approximate the rate of infiltration through the bottom of the bog ditch, are on the order of 6 inches/year. This rate is considerably lower than the annualized rate of surface water decline (approximately 81 inches/year) that occurred during the period of observation over a time when no precipitation fell. Consequently, processes other than infiltration (e.g., evaporation) most likely affect surface water level decline to a far greater degree than infiltration in the Sphagnum Bog Wetland ditch. This conclusion is consistent with the hypothesis that surface water is perched in the bog ditch.
- Based on the results of this analysis, it is concluded that there is no direct connection between fluctuations in surface water and groundwater levels at the Sphagnum Bog Wetland. Therefore, the FS-1 ETD system-induced groundwater declines observed at the Sphagnum Bog Wetland, and reported in AFCEE (2005b), do not cause the surface water in the surrounding bog ditch to decline (i.e., the observed surface water level fluctuations at this bog are independent of the changes in local groundwater levels). As a result, a pumping plan to operate the FS-1 ETD system differently than it was originally designed is unnecessary.

## 4.2 WETLAND EAST OF THE K1 BOG

- Groundwater levels at the wetland east of the K1 Bog were strongly influenced by antecedent precipitation. The degree of correlation between precipitation rates and groundwater levels was similar to that seen at the Sphagnum Bog Wetland; however, the magnitude of the groundwater response at the wetland east of the K1 Bog was smaller.

- No relationship could be discerned between the groundwater levels at the wetland east of the K1 Bog and the minor variations in the pumping rates of the FS-1 extraction wells during the period of observation. However, the system shutdown in 2004 (AFCEE 2005b) showed that groundwater levels in piezometer 36PZ4237 rose by approximately 0.7 feet when all of the wells were turned off for a period of days.
- Surface water levels in the wetland east of the K1 Bog are stabilized by the weir boards installed in the outlet channel, except during periods of relatively dry weather.
- When the surface water level is lower than the crest of the outlet weir, the greatest influence on the water level is the antecedent precipitation rate.
- A lack of data during the observation period when surface water levels were not controlled by the weir precluded statistical analysis of the relationship between surface water and groundwater levels.
- Groundwater levels were consistently higher than surface water levels with the FS-1 ETD system operating. Therefore, the FS-1 ETD system-induced groundwater declines observed at the wetland east of the K1 Bog, and reported in AFCEE (2005b), do not cause the surface water in the wetland to decline (i.e., the observed surface water level fluctuations at this wetland are independent of the changes in local groundwater levels). As a result, a pumping plan to operate the FS-1 ETD system differently than it was originally designed is unnecessary.

## 4.3 REFERENCE WETLANDS

- Surface water levels in the abandoned cranberry bog that was monitored as a reference wetland responded to changes in antecedent precipitation rates in a manner very similar to that observed in the Sphagnum Bog Wetland and the wetland east of the K1 bog.
- Surface water levels at Vernal Pool 2 showed a different pattern of variation than at any of the other sites studied. Apparently, this wetland is substantially affected both by precipitation and by other unidentified factors.

# 5.0 RECOMMENDATIONS

Based on the conclusions of this hydrologic assessment, a pumping plan to mitigate potential impacts to surface water levels caused by the operation of the FS-1 ETD system at the Sphagnum Bog Wetland and the wetland east of the K1 Bog is not necessary because: (1) the results of the assessment indicate that the effects of groundwater fluctuations on the surface water were negligible in comparison to the influence of natural variation in the rate of precipitation at both wetlands; (2) surface water in the perimeter ditch at the Sphagnum Bog Wetland is considered to be perched because of the fine-textured, low permeability, sediments immediately underlying the bottom of the ditch; and (3) surface water levels in the wetland east of the K1 Bog are largely controlled by the weir boards installed in the outlet channel.

Additionally, inasmuch as the ETD system is not affecting the surface water levels at the two ecosystems of concern, the frequency of the hydraulic monitoring at the Sphagnum Bog Wetland and the wetland east of the K1 Bog should be reduced from weekly to semiannually for both piezometers 36PZ4236 and 36PZ4237. Lastly, staff gauge monitoring should be eliminated both at these two ecosystems of concern and at the two reference wetlands.

## 6.0 REFERENCES

AFCEE (U.S. Air Force Center for Environmental Excellence). 2007 (February). Fuel Spill-1 2006 Summary Letter Report. 337105-SPEIM-FS1-SLR-001. Prepared by CH2M HILL for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

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Freeze, R Allen. and John A. Cherry. 1979. Groundwater. Prentice Hall, New Jersey. 604 pp.

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29 March 2007

Mr. Jonathan S. Davis
Remediation Program Manager
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SUBJECT: AFCEE 4P F41624-03-D-8595; Task Order 0384
MMR SPEIM/LTM/O&M Program
CDRL #A001H
**Final Fuel Spill-1 2005 Hydrologic Assessment of Two Ecosystems of Concern Technical Memorandum**

Dear Mr. Davis:

As directed by the Air Force Center for Environmental Excellence, CH2M HILL is hereby distributing copies of the *Final Fuel Spill-1 2005 Hydrologic Assessment of Two Ecosystems of Concern Technical Memorandum* dated March 2007. Enclosed are six bound copies, one unbound copy and nine compact disc (CD) copies. Copies are also being sent to the appropriate agencies. This final technical memorandum includes the revisions presented in the response to comment letter dated 08 March 2006 and the memorandum of resolution dated 05 May 2006.

In addition, as agreed during the comment resolution with the Town of Mashpee, sediment cores were re-collected in August 2006 and analyzed during November 2006. The results of the 2006 sediment testing were presented to the town during the 23 January 2007 meeting, where it was agreed the technical memorandum would be finalized with the incorporation of the 2006 sediment results.

If you have any questions or comments, please contact Mr. Mike Minior at (508) 968-4670, extension 4672.

Sincerely,

CH2M HILL

Patricia de Groot

Patricia de Groot, P.G., L.S.P.
Program Manager

Enclosures: (6 bound, 1 unbound & 9 CDs)

c. Melvin Alli, AFCEE/ICA (1 CD)
AFCEE/MSCD (1 CD)
HSW/PKVB (1 w/o attach.)
Mike Minior, AFCEE
Rose Forbes, AFCEE
Denis LeBlanc, USGS (1 CD)
David Williams, DPH (1 CD)
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